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A Novel Binarization Algorithm for Ballistics Imaging Systems

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Abstract—The identification of ballistics specimens from imaging systems is of paramount importance in criminal investigation. Binarization plays a key role in preprocess of recognizing cartridges in the ballistic imaging systems. Unfortunately, it is very difficult to get the satisfactory binary image using existing binary algorithms. In this paper, we utilize the global and local thresholds to enhance the image binarization. Importantly, we present a novel criterion for effectively detecting edges in the images. Comprehensive experiments have been conducted over sample ballistic images. The empirical results demonstrate the proposed method can provide a better solution than existing binary algorithms.

Keywords—Ballistics, image processing, binarization

I. INTRODUCTION

The identification of ballistics specimens from imaging systems is of paramount importance in criminal investigation[1, 2]. The characteristic marks on the cartridge and projectile of a bullet fired from a gun can be recognized as a fingerprint for identification of the firearm[3]. Traditional methods for the identification of these marks are based on incident light microscopy[4]. However, the assessment by the ballisticsian of the similarity between comparable marks on respective ballistics specimens from crime scenes and test firings is based on the expertise and experience. In this regard, the traditional methods of matching marks have some inherent difficulties and entail an element of subjectivity[5]. Therefore, the development of automatic firearm identification is highly demanded by real applications.

Several ballistics identification systems have been available in both a commercial form and a beta-testing state. The two major international ballistics imaging systems are manufactured by the IBIS Company in Montreal, QC, Canada, and the FBI (Drugfire) in USA. A Canadian company called Walsh Automation has also developed a commercial system called “Bulletproof”, which can acquire and store images of projectiles and cartridge cases by searching the image database for particular striations on projectiles. However, it is required to match the impressed markings or striations by user on the projectiles. This kind of limitation makes the system very difficult to use. Our previous work[6-8] has developed a novel identification

system called Fireball Firearm Identification System. This system is able to identify, store, and retrieve the images of cartridge case heads. It also can obtain position metrics for the firing-pin impression, ejector mark, and extractor mark. The limitation of this system is that the position and shape of the impression images need to trace manually by the user. The FireBall system needs further development and improvement.

To implement the automatic identification of cartridge, we need to binarize the image before extracting its features. The binarization is a key step in image preprocessing. The quality of the final result of identification is heavily dependent on the quality of the binary output[9-12]. Until now, various binarization techniques have been proposed. There is no fit-in-all method that can be applicable to different kind of images, even is ‘good’ for some certain type of images. Meanwhile, the performance of binarization is very sensitive to the choice of the parameter values, i.e., threshold or threshold surface. Mehmet[13] categorizes the thresholding methods into six groups according to the information they are exploiting: histogram shape-based thresholding methods; clustering-based thresholding methods; entropy-based thresholding methods; thresholding based on attribute similarity; spatial thresholding methods and locally adaptive thresholding. We can also divide those thresholding methods into two categories, i.e., global thresholding and local thresholding. If only one threshold is used for the entire image then it called global thresholding. On the other hand, if a few thresholds are used for the entire image and each threshold based upon a part of the image, then it called local thresholding.

The global thresholding algorithm works well in situations where there is a reasonably clear valley between the modes of the histogram related to objects and background. Otsu[14] is a good global thresholding algorithm. Unfortunately, it is not easy to find a right global thresholding when an image has noise or uneven illumination or poor contrast.

The local thresholding methods choose variable thresholds based on the local information in an image[15-18]. They overcome the drawbacks of global thresholding algorithms. In this paper, we utilize various local thresholding algorithms to binarize cartridge images in ballistic imaging system, such as Chow and Kaneko[15],

Yanowitz and Bruckstein[17]. However, we can hardly get the satisfactory results because the images we process have not only uneven illumination and poor contrast, but also complex and noisy.

In this paper, we propose a new algorithm for the cartridge binarization, which combines the global thresholding and local thresholding. We utilize the global and local thresholds to enhance the image binarization. Importantly, we present a novel criterion for effectively detecting edges in the images. The experiment results indicate that the proposed algorithm performs better than those with the existing algorithms.

The proposed algorithm has the following advantages: 1. Edges detecting is more accurate due to the edges enhancement operator that enhances edges and depress the non-edges. 2. Reduce the false objects benefit from the combination of the local thresholding and global thresholding; 3. Reduce noisy points by removing small size blocks in the output image.

The rest of this paper is organized as follows: Section II, introduces the existing algorithms, which are used in comparative studies. The binarization algorithm is described in Section III. Experimental results are presented in Section IV. Section V concludes the paper.

II. MAJOR BINARIZATION TECHNIQUES

In order to make a comparison with the proposed algorithm, we discuss one classical global thresholding Otsu[14] and two threshold algorithms, i.e., Chow and Kaneko[15], Yanowitz and Bruckstein[17].

Otsu is a typical and popular global thresholding algorithm. It divides the image into two parts (namely foreground and background) by threshold. The basic idea of Otsu aims to find an optimal threshold that gives the best separation between the two classes in terms of their intensity values. In order to obtain an optimal threshold, the algorithm tests all possible thresholds from one to maximum intensity, in order to find the maximum variance between the two classes.

Chow and Kaneko[15] propose another algorithm to divide the image into nonoverlapping cells of equal area forming a regular grid, and then determine the (sub)histograms of the grey levels of pixels in each cell. This method was further studied and developed by Nakagawa and Rosenfeld[8]. The sub-histograms that are judged to be bimodal are used to determine local threshold values for the corresponding cell centers, while the local thresholds are interpolated over the entire image to yield a threshold surface. It can work well when the objects of interest and the background occupy regions of reasonably comparable size in a cell. Otherwise, the method often fails because the cell only contains objects or background pixels.

Yanowitz and Bruckstein[17] use edges and gray level information to obtain threshold surface. The algorithm computes the gray level gradient magnitude from a smooth version of the original image. The gradient values are then thresholded and thinned by local maxima that direct thinning process. Locations of these local gradient maxima are taken

as boundary pixels between object and background. The corresponding gray levels in the image are taken as the local thresholds. The sampled gray levels are then interpolated over the entire image to obtain an adaptive threshold surface. The algorithm has made a great improvement compared with that of Chow and Kaneko[7]. The efficiency is however dependent on the correct detection of edges in the image. Consequently, it may yield “ghost” objects and stains in the segmented image when edges are mistakenly detected.

III. ALGORITHM

A. Algorithm

The algorithm based upon the global thresholding and local thresholding. The pixels in the image have been divided into two categories, namely edge pixels and non-edge pixels. The global threshold has been adopted to the non-edge pixels. Correspondingly, the local thresholds have been used to the edge pixels. In order to remove the noisy points, the size of each object in binary image has been measured. The objects whose size is less than the size of 1/3000 of entire image will be removed.

The algorithm is detailed as follows:

1. Smooth the original image by the Median Filter with 5×5 size. It aims to reduce the noise that may produces by camera, lighting conditions, etc.
2. Stretch the smoothed image from step 1. This step is important because the low contrast image due to the foreground and the background of cartridge made by same materials is harmful to the subsequent process.
3. Detect the edges in stretched image using Sobel operator, then enhance the edges and depress the non-edges, and finally generate an edge binary image by binarizing the enhanced and depressed image.
4. Compute the global threshold in stretch image by Otsu algorithm[14], and compute the local thresholds to the pixels on the edge image.
5. Binarize the stretched image using global threshold in non-edge pixels and local thresholds in edge pixels.
6. Removing the noisy blocks and obtain a satisfactory binary image. The binary image from step 5 may contain some noisy blocks due to the noisy original image or rough surface of cartridge. The size of these blocks is small. We can clear them by removing small-size blocks.

B. Illustrating Examples

1) Smooth the original image.

For practical applications, the quality of the image acquired by camera can be noised by many factors such as the lighting conditions, the materials of the cartridge, the original texture on the surface of cartridge and cameras itself. Strong noise would lead the difficulties in binarization and even get wrong results. Low-pass filter operation is a good way to reduce the noisy effects mentioned above. We test conventional low-pass filters both on spatial domain (Averaging Filter and Median Filter) and on frequency domain (Ideal Low-pass Filter, Butterworth Low-pass Filter and Gaussian Low-pass Filter). After comparing those filters mentioned above, we find that the Median Filter can not only

reduce the noise, but also keep the sharp edges. Since sharp edges are important for subsequent process, we decide to select the Median Filter with 5×5 size.

2) Gray stretch.

From the Figure 1(a), the foreground letters and background almost have the same gray. The low contrast may result from the foreground and the background made by same materials. We binarize the image using Otsu algorithm[14] and get the result in Figure 1(e). We can hardly get the useful information from the Figure 1(e). By analyzing the histogram of the image Figure 1(c), we can find that the gray value in all pixels concentrates in a narrow range, which is very disadvantageous to binarize the image. In other words, we prefer that the gray value in enhanced image covers all available gray space, rather than mainly distributing in a narrow range. In order to enhance the contrast of the image, we perform a contrast enhancement in equation (1) to expand the gray range.

$$f(x) = \begin{cases} 0 & x < x_1 \\ \frac{y_2 - y_1}{x_2 - x_1} (x - x_1) + y_1 & x_1 \leq x \leq x_2 \\ 255 & x > x_2 \end{cases} \quad (1)$$

where x_1 denotes the minimum gray value, x_2 denotes the maximum gray value, x denotes the gray value in original image, and $f(x)$ denotes the gray value in processed image.

The example is given in Figure 1. The original image is shown in Figure 1(a). The image in Figure 1(b) has been enhanced and the contrast has a great improvement. This can also be evidenced by the change of the histogram. The distribution of the histogram in Figure 1(d) is wider than that in Figure 1(c). The image in Figure 1(f) is the result binarized on image Figure 1(b) using OTSU algorithm[14]. Figure 1(f) has more information than Figure 1(e), but it still doesn't include enough information.

3) Compute the global and local thresholds.

In previous section, we employ the gray stretch to enhance the image, and then binarize the enhanced image. We find that the binarized image in Figure 1(f) is still unsatisfactory. The use of global threshold cannot meet our requirements. Meanwhile, it is also difficult to find local thresholds that are used to binarize images. Yanowitz and Bruckstein[17] take pixels with local gradient maxima as boundary pixels between object and background. The corresponding gray levels in the image are taken as local thresholds. This is verified by the experiments over cartridge head images. Apparently, neither global nor local thresholding algorithm can fully solve our problems.

After extensive experiments, we find the 'good' results are obtained using the global thresholding to non-edge pixels and using the local thresholds to edge pixels. The global threshold can be obtained by Otsu algorithm, while local threshold in each pixel is the mean gray value with neighborhood with size 5×5 .

The popular edge detection methods are based on gradient or zero crossing. The gradient method detects the edges by computing value in the first derivative of the image. The zero crossing method searches for zero crossings in the

second derivative of the image to find edges. For detection of edge, various detection operators can be used. Most of these are applied with convolution masks and most of these are based on differential operations. We adopt Sobel operator as a mask of edge detector. Sobel operators include vertical, horizontal, 45 degree and 135 degree directions operation masks. In our experiments, the Sobel operators are used to extract edges of letters on the images of cartridge head. Because the letters on the image almost have a 45 or 135 degree direction, so we use 45 and 135 degree mask.

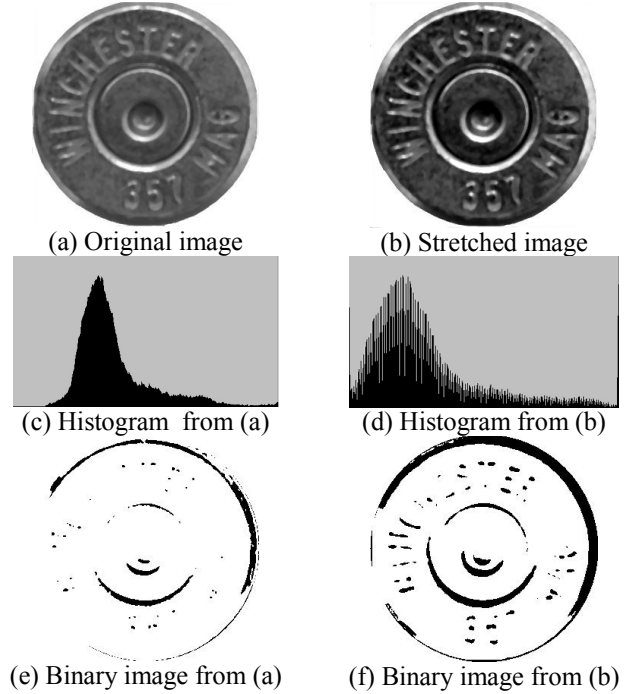


Figure 1. Gray stretch

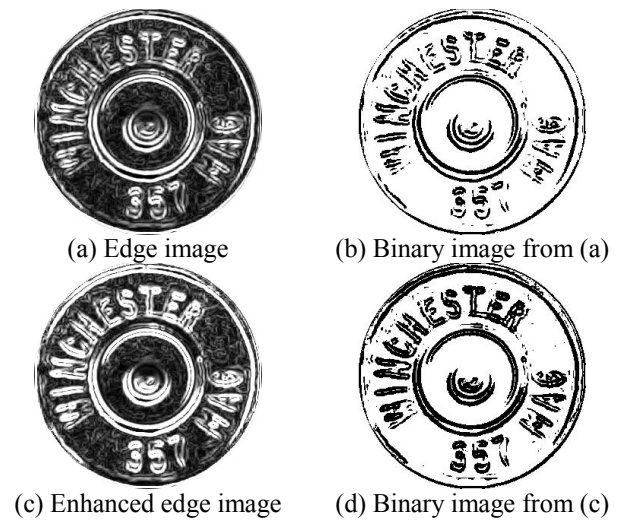


Figure 2. Edge images

The edge image obtained by convolving the images with the Sobel masks is shown in Figure 2(a). Its binary image in

Figure 2(b) has noncontinuous edges due to the low contrast between the edges and the background, which needs further refinement.

In order to improve the accuracy of edge, we present a novel criteria for effectively identifying the edges, detailed in equation (2).

$$f_1(x, y) = f(x, y) \times \frac{\text{gradient}(x, y)}{\text{AvgGradient}(x, y)} \quad (2)$$

where $f(x, y)$ denotes the input image, $\text{gradient}(x, y)$ presents the gray value of pixel, and the $\text{AvgGradient}(x, y)$ is the mean gray of input image. It is clear that the $\text{gradient}(x, y)$ of pixels in edges is greater than $\text{AvgGradient}(x, y)$, so we can find $\text{gradient}(x, y)/\text{AvgGradient} > 1$. Similarly, the $\text{gradient}(x, y)$ of pixels in non-edges is smaller than $\text{AvgGradient}(x, y)$, i.e., $\text{gradient}(x, y)/\text{AvgGradient} < 1$. Based on equation (2), the gray values in edge pixels will be increased, while the gray values in non-edge pixels will be decreased.

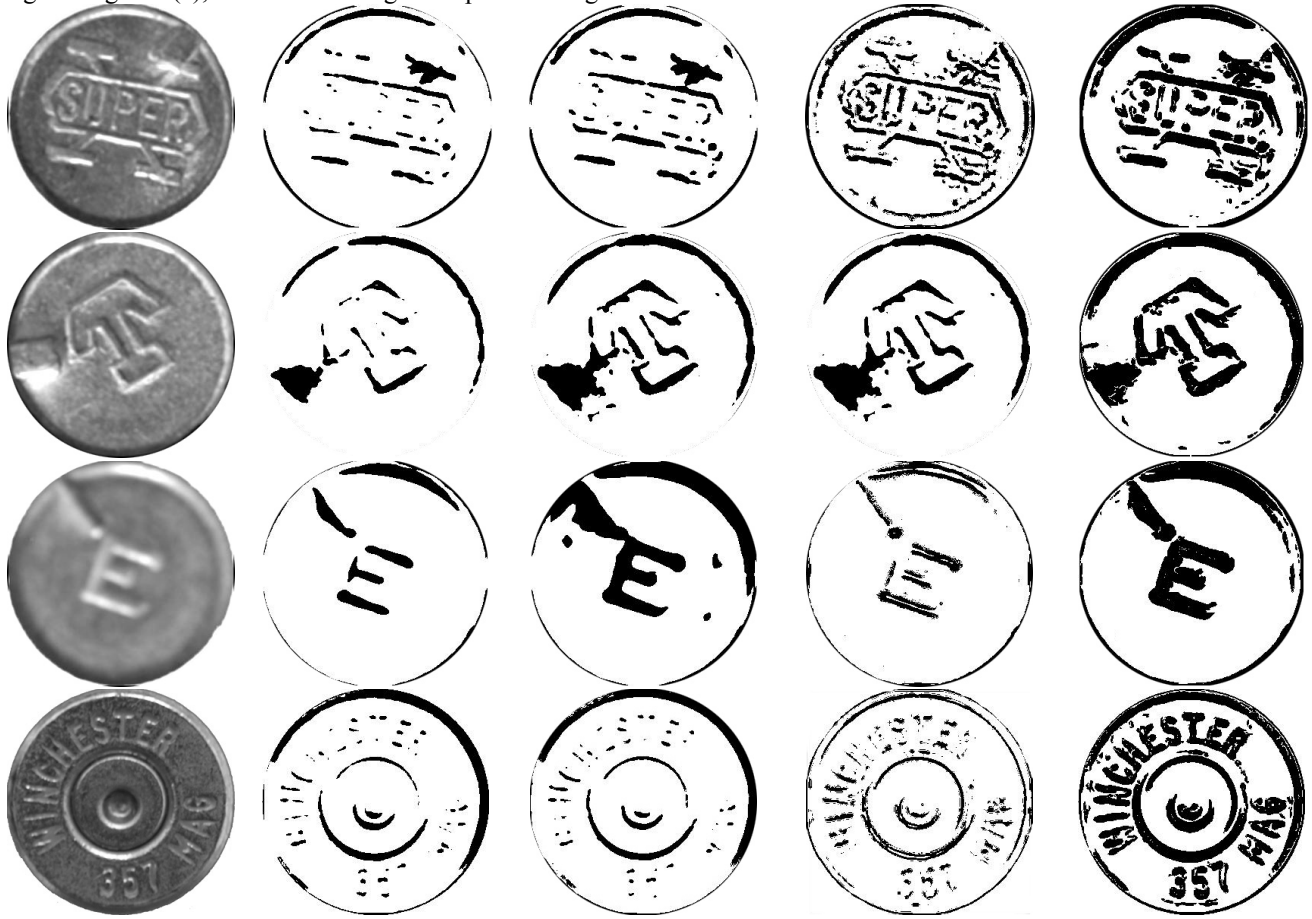
Figure 2(c) is the enhanced image operated by equation (2). Compared with Figure 2(a), the enhanced image has a great improvement. Correspondingly, Figure 2(d) is better than Figure 2(b).

4) Binarization.

By comparing edge image in Figure 2(d) with original image in Figure 1(a), we find the foreground pixels in Figure

1(a) almost close black pixels in Figure 2(d), while the background pixels in Figure 1(a) almost near white pixels in Figure 2(d). Therefore, we take Figure 2(d) as a mask of thresholding selection. The pixels in the neighborhood with size 5×5 of black pixel adopt the local threshold that is the mean gray value of its neighborhood with size 5×5 , while the global thresholding is adopted in the remaining pixels. The steps of binarization are detailed as follows:

1. Compute the global threshold of the input image $f(x, y)$ in Figure 1(b) by Otsu algorithm[14].
2. Declare a $w \times h$ threshold array $T(x, y)$, where w and h are separately the width and height of input image.
3. Obtain the edge binary image $g(x, y)$ based upon the algorithm in last Section.
4. Scan the edge binary image $g(x, y)$. If the gray value of pixel in $g(x, y)$ is 1 (black point), the pixels in its neighborhood with size 5×5 use the local thresholding, which is a gray mean of this neighborhood pixels, and save this threshold into corresponding elements of $T(x, y)$. On the other hand, if the value of pixel in $g(x, y)$ is 0 (white point), save the global thresholding into the corresponding element of $T(x, y)$. Thus, we can get the threshold surface that includes threshold of each pixel in input image $f(x, y)$.
5. Binarize the input image $f(x, y)$ depend upon the thresholds in array $T(x, y)$ and obtain the binary image.



Original image

Otsu

Chow and Kaneko

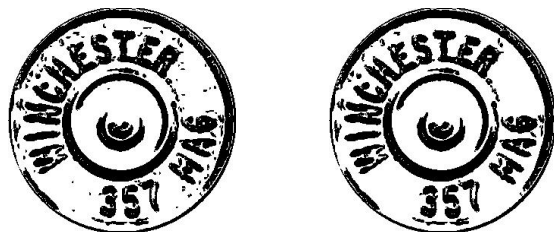
Yanowitz and Bruckstein

Proposed algorithm

Figure 4. Results of experiments

5) Remove noisy block.

Normally, images may contain some noisy. For example, Figure 3(a) contains some noisy blocks. We need to filter the noisy embedded in images. For our ballistics Images, we find the size of noisy blocks is less than 1/3000 of the entire input image, while the size of objects is greater than 1/1000 of the entire input image. So we remove the blocks whose size is less than 1/3000 of the entire input. The results are illustrated in Figure 3(b).



(a) Binary image (b) Remove small size blocks
Figure 3. Binary image

IV. EXPERIEMENTS

A. Smaple Images

We choose four typical cartridges images, shown column 1 in Figure 4. Every image size is 300×300 pixels. In Figure 4, images in row 1 has a complex signs and letters with a rim fire; images in row 2 has a simple letter T in center and also has a rim fire, which almost has a same gray between the letter and the background; images in row 3 is blur due to the incorrect focus of camera; images in row 4 has so many letters at the outer with a center fire.

B. Results and discussion.

In order to make a comparison with the proposed algorithm, we compare performance of the proposed algorithm with those of Otsu[14], Chow and Kaneko[15] and Yanowitz and Bruckstein[17]. The Otsu is a typical adaptive global thresholding algorithm, while the other two methods are the local thresholding. Figure 4 shows the results of these algorithms. The column 2, 3, 4, 5 are separately the results of Otsu, Chow and Kaneko, Yanowitz and Bruckstein and proposed algorithm. The proposed algorithm performs better than the others

V. CONCLUSION

The binarization is of great importance for identification of cartridges. In this paper, we propose a novel binary algorithm for cartridge images. The criteria proposed can increase the efficiency of edge detection. The experimental results demonstrate that the proposed algorithm can provide a better solution to the noisy and low illumination ballistics images.

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